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RESEARCH PAPER

Comparative Analysis of On-Site Free-Hand Chainsaw Milling and Fixed Site Mini-Bandsaw Milling of Smallholder Timber

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Abstract Sawing trials were conducted to determine the green-off sawn (GOS) timber recovery rates of chainsaw milling and mini-bandsaw milling and determine the potential returns from timber sales (stumpage value) of smallholder tree farmers in the Philippines. The GOS recovery rate of 52 % for fixed site mini-bandsaw mills was found to be significantly higher than that of on-site chainsaw milling (39 %). It was further found that when hauling distance from barangay to customers exceeds 13 km, chainsaw milling generates higher revenue due to the lower transport cost of sawn timber.

Keywords On-farm timber processing · Small-scale sawmill · Green-off-saw timber recovery · Smallholder tree farms

Introduction

Chainsaws are used widely in lumber milling in the Philippines. For example, Macandog et al. (1998) and Masipiqueña et al. (2008) noted the use of chainsaws in smallholder timber processing, while van der Pleog (2010) discussed the role of chainsaw milling in illegal timber poaching in natural forests. Smallholders adopt on-site chainsaw milling because chainsaws are readily available and are inexpensive to purchase or hire to fell trees and convert them into sawn timber. Further, timber on smallholder tree farms is typically of low quality and hence on-farm chainsaw milling is considered a value-adding option for farmers, especially

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for short and low diameter logs which are not likely to be suitable for fixed-site sawmills. Mini-bandsaw milling is an alternative method of milling smallholder timber in the Philippines. In Northern Mindanao, Bertomeu (2008) reported that a large proportion of smallholder timber is processed by mini-bandsaw mills. Mini-bandsaw mills would generally be expected to have a higher lumber recovery rate than chainsaw milling due to their smaller kerf (e.g. see Smorfitt et al. 2001, 2006). Some timber retailers have mini-bandsaw mills for re-sawing flitches to smaller lumber dimensions. However, mini-bandsaw mills are often located a considerable distance from smallholder tree farms and transport of timber to mills in some cases is uneconomic. The scarcity of timber for local markets has meant that chainsaw milling on-site appears to be attractive to smallholder tree growers distant from bandsaw mils. In Australia, the uneconomic transport distances of sawmills from woodlots encourages on-site processing of timber from tree farms (Stewart and Hanson 1998, Stewart 1999) although portable bandsaw mills and portable circular mills are widely used instead of chainsaw mills (Smorfitt et al. 1999, 2003).

Freehand chainsaw milling is prevalent in many developing countries. For example, Pinard et al. (2007) and Marfo (2010) described the domestic timber industry in Ghana as being dominated by chainsaw-milled lumber. In Meru District in Kenya, chainsaws are illegally used to produce timber from trees on farms due to closure of fixed-site sawmills following the moratorium on logging in natural forest in 1990 (Pasiecznik and Carsan 2006). In the Tanimbar Islands in Indonesia, tree felling in natural forests and timber milling are primarily done with chainsaw (Roda 2005). Cerutti et al. (2010) found that a considerable amount of domestic timber in Congo Basin countries (Congo, Cameroon, Gabon and Central African Republic) including some of their exported timber is produced with chainsaws. It is to be noted however that some of these countries—including Ghana and Congo Basin countries—have banned chainsaw milling to deter illegal logging, although the bans have limited effect (Cerutti et al. 2010). In the Philippines, a registration and permit system for chainsaws is enforced to deter illegal timber poaching. However, van der Pleog (2010) noted that chainsaw milling is used in the illegal timber trade in Northern Philippines and some illegal logging no doubt occurs in other regions of the country.

On Leyte Island and elsewhere in the Philippines, smallholder tree farmers are paid for timber products based on net volume of green-off-saw timber. Farmers sometimes sell standing trees and logs to saw millers, and if they do the payment is still based on recoverable sawn timber volume estimated from the log small end diameter under bark (sedub). It is however difficult to obtain accurate data on the sawmilling activities because timber millers are nervous to report details of their resource use. Apart from this being a traditionally tight-lipped group in many countries, there is the concern in the Philippines that some of the resource has been illegally logged (especially for native species) and hence there is a fear of increased taxation and of prosecution (Cedamon et al. 2011). Some smallholder timber is sold directly to customers—e.g. families building or renovating homes—sometimes with chainsaw operators or owners acting as middlemen. Timber retailers in town centres prefer to purchase flitches and sawn timber rather than logs from smallholders due to lower transport cost and lack of saws large enough to do their own flitching.

Advantages of free-hand chainsaw milling include low capital outlay and mobility for millers. Disadvantages include low sawn timber recovery due to wide kerf, which is further reduced when unskilled operators are involved, and high risk for injuries to operators. Wyatt (1996) concluded from his study in Vanuatu that chainsaw milling is generally not capable of producing large quantities of sawn timber for a full-time sawmilling business. However, it is operationally suitable when timber volume is low and tree farms are small and fragmented in the landscape. Samuel et al. (2007) found the green-off-saw (GOS) recovery rate (percentage of volume of sawn timber to debarked log volume) of free-hand chainsaw milling ranges from 5 to 61 %. Arancon R Jr (1997) estimated the GOS recovery rate of chainsaw milling of coconut lumber in the Philippines to be 33 %. In contrast, Blackwell and Walker (2006) estimated a GOS recovery rate ranging from 40 to 65 % in large and technologically-advanced sawmills.

In that the smallholder timber product is sawn timber rather than sawlogs, it is necessary to understand how the sawn timber recovery rate of sawmilling options available to smallholders affects recoverable merchantable sawn timber yield and thus the financial return from tree farming. Sawing trials were conducted on Leyte Island to estimate the average GOS recovery rate of free-hand on-farm chainsaw milling and off-farm mini-bandsaw milling.[1] The next two sections describe the methodology employed in the sawing trials. GOS recovery rates of free-hand chainsaw milling and fixed site mini-bandsaw milling, in relation to operator sawing experience, are then compared. A financial analysis of the two sawmilling options for smallholders is presented. Finally, key study findings are discussed and conclusions presented.

Organising the Sawing Trial

Trials of sawing gmelina[2] (*Gmelina arborea* Roxb.) logs were conducted in the municipalities of Bato and Matalom on Leyte Island in the Philippines. In each municipality, sawing trials were conducted with a mini-bandsaw owner-operator, chainsaw operator, tree farmer, and *carabao* owner.[3] The enterprises of co-operators, the bandsaw mills, and the condition of participation in the sawing trials are summarized in Table 1.

The mini-bandsawmill in Bato (Fig. 1a) had a 3 hp electric motor while in Matalom (Fig. 1b) had a 15 hp electric motor. Manual log feeding was practiced in both mills. The mini-bandsaw mill in Bato produced lumber for sale while the mill

[1] The GOS recovery rates of these two milling technologies determined from the sawing trials have been used in a wider research project in modelling recoverable lumber volume from smallholder gmelina tree farms, evaluating financial performance of thinning smallholder gmelina tree farms, predicting smallholder gmelina lumber supply, and determining optimal milling and transport options for smallholder timber through transhipment modelling.

[2] Gmelina is the most widely grown timber species on smallholder tree farms on Leyte Island, Philippines.

[3] Carabaos (water buffalos) are used by Filipino farmers mainly to assist in various farm tasks including plowing and hauling.

Table 1 Descriptions of mini-bandsaw milling trial co-operators and conditions for participation in the sawing trial

Feature of sawing trial	Bato	Matalom
Date of sawing trials	September 2008	February 2009
Description of enterprise	Mini-bandsaw milling for lumber selling	Mini-bandsaw milling to produce lumber for furniture making
Bandsaw description	Fixed-site, 3 hp electric motor, about 4.8 m length blade, manual feeding, with flywheels made of glued plywood (Fig. 1a)	Fixed-site, 15 hp electric motor, about 6.4 m length blade, manual feeding, flywheels made of glued plywood (Fig. 1b)
Condition in participating in the sawing trial	Researcher met half of log hauling and milling cost	Researcher met the stumpage cost of the trees for chainsaw milling

in Matalom produced lumber for furniture making by the owner. Both mini-bandsaw mill co-operators used timber for their main business, and the researcher paid only part of the costs of the sawing trials. The mini-bandsaw miller in each municipality took all the lumber produced from the sawing trials, and the researcher paid only part of the milling cost.

Two different chainsaws but of the same make and model were used in the trials. Both had a guide bar length of 63 cm, were petrol (gasoline) powered, and weighed about 15 kg including the guide bar and chain. A ‘ripping chain’ was used with a kerf of approximately 9 mm. The kerf of the mini-bandsaws was 5 mm.

Fig. 1 **a** Bandsaw operation in the Bato sawing trial. **b** Bandsaw used in the Matalom sawing trial, illustrating the large flywheel

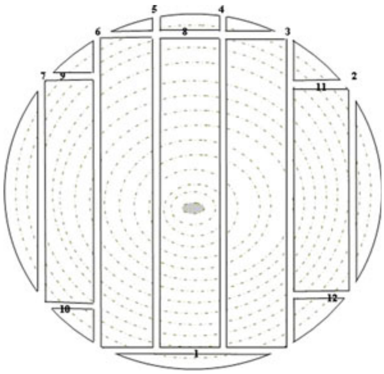

Fig. 2 Sequence of board cutting in 'live' sawing employed in the sawing trials

'Live' or 'plain' sawing of logs was adopted for both saw types, to maximize sawn timber recovery.[4] Each log was positioned and secured for sawing by cutting a slab (cut 1, Fig. 2). The log was then turned on its side and the boards cut following the sequence depicted in Fig. 2. The board thickness was constant at 2 inches (5.08 cm) except for small logs for which slicing to 2 inches thickness was not possible. Nominal sizes of sawn board were recorded and sawn timber volume was aggregated for each log.

The equipment operators were interviewed to obtain information about their sawing experience. The chainsawer in Bato had 20 years experience in sawing timber while the Matalom chainsawer had 25 years experience, and contract chainsawing was his main source of income. The bandsawer for the Bato sawing trial had three years experience (comprising about 2,000 h) in a mini-bandsaw mill. The Matalom bandsawer had one year bandsawing experience (about 900 h of sawing, including 100 h apprenticeship with the bandsaw owner). Notably, he was the only saw operator who had undertaken any formal education or training in operation and maintenance of sawing equipment.

Data Collection and Analysis

A total of 105 relatively straight logs were sawn, 48 by chainsaw and 57 by bandsaw. The felled trees were cut into log sections, and diameter over bark at both ends and length were measured. Bark thickness was deducted from the diameter over bark to estimate diameter under bark.[5] Volumes under bark of *unsawn logs* were calculated using the Smallian formula of $0.7854 \times (\text{SEDUB}^2 + \text{BEDUB}^2)/$

[4] 'Live sawing' or 'through and through' is the simplest cutting method and most commonly practiced by sawmills cutting small-diameter logs. Here the logs are sawn by a series of parallel cuts, rather than breaking down the log before sawing to required thickness (How et al. 2007). The rectangles in Fig. 2 represent cross sections of the boards while the spaces in between these rectangles represent saw cuts and the curved exterior sections represent waste wood.

[5] Log diameters under bark were calculated as the difference between the over-bark diameter and the recorded bark thickness, with big-end-diameter under bark (bedub) derived as big-end diameter over bark less 2 × bark thickness at big-end.

Table 2 Summary of logs and sawn timber dimensions from the sawing trial

Log diameter (diameter under bark, cm)	Number of logs milled	Average log diameter (cm)	Average log length (m)	Average bark thickness at big end (cm)
11–14.99	15	13	1.29	0.62
15–19.99	37	17	1.56	0.72
20–24.99	26	21	1.39	0.81
25–29.99	18	27	2.05	1.02
30–34.99	8	31	2.41	1.06
35–39.99	1	36	1.29	1.70
Weighted average		21	1.63	0.81

2 × log length (modified from West 2004), with length measurement in metres, log diameter in centimetres and log volume in cubic metres. The *sawn timber volume* from each log was calculated as the sum of the nominal sawn timber volume[6] from each board produced from the log. The recovery rate for green-off-saw timber from each log was calculated as the total volume of sawn boards (m^3) obtained from the log divided by the estimated log volume under bark (m^3). Volume calculations were made in Excel and the raw data were exported to SPSS to derive descriptive statistics of the profiles of logs sawn and timber boards. For each log diameter class, the distributions of number of logs, average log diameter (under bark), average log length and average big-end bark thickness are presented in Table 2. More than half of the logs sawn in the trials had average diameter under bark of 15–25 cm.

Figure 3 presents a scatter plot of log diameter (average of sedub and bedub) and GOS recovery rate for chainsawn and bandsawn logs. The regression equations for GOS recovery rate versus log size, together with test statistics for the slope coefficient and the r^2 (coefficient of determination) values, were estimated as:

For bandsawn logs: recovery rate = −0.5148 × log diameter + 0.6241 ($t = -1.76$, $p = 0.08$, $r^2 = 0.0531$).
For chainsawn logs: recovery rate = −0.1109 × log diameter + 0.4108 ($t = -0.46$, $p = 0.65$, $r^2 = 0.0045$).

Give the lack of significant relationship between variables for both sawing methods, it was assumed for subsequent analysis that the sawn timber recovery rate is independent of log diameter.

Two-way analysis of variance (ANOVA) was carried out in SPSS to determine whether the type of saw (chainsaw or bandsaw) and the operator affected the sawn timber recovery rate. The hypothesized model for the underlying log population is

$$x_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}, \quad i = 1 \text{ to } a,\ j = 1 \text{ to } b,\ k = 1 \text{ to } n$$

where x_{ijk} is recovery rate, α and β are treatment effects, $\alpha\beta$ is the *interaction* between them, and ε_{ijk} is a random error term. Here, i represents saw type,

[6] A nominal sawn timber volume is calculated based on the nominal dimension of sawn timber (e.g. 5 cm × 5 cm × 2.4 m), which can vary slightly from actual dimensions of sawn timber.

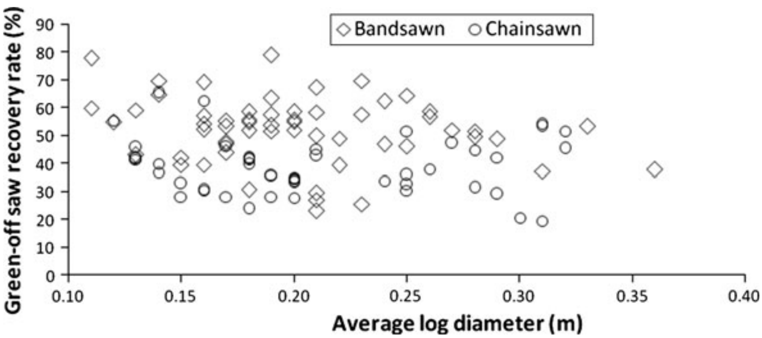

Fig. 3 Scatter plots of GOS recovery rate by average log diameter

j represents operator and *k* represents individual log. In the ANOVA the following questions are evaluated:

1. Is the sawing recovery rate for bandsaws the same as for chainsaws?
2. Is the sawing recovery rate for Bato operators the same as for Matalom operators?
3. Is there interaction between saw type and operator as determinants of recovery rate?

Interviews of key informants (bandsaw operators, tree farmers, chainsaw operators and carabao skidders involved in the trials) and *participant observations* were conducted to estimate costs and revenue of small-scale sawn timber processing. Costs related to obtaining harvest and transport permits are not included in the financial analysis because these are fixed regardless of sawing method. The financial analysis was conducted in Excel, in which the Table and Scenario functions were used to perform sensitivity and scenario analysis.

Sawing Recovery Rate by Saw Type and Operator

The GOS recovery rates of bandsaw and chainsaw mills in the Bato and Matalom sawing trials are summarised in Table 3. The average GOS recovery for bandsaw

Table 3 Summary statistics for sawing trial data by saw type and trial site municipality

Saw type	Mean recovery rate of Bato operator (%)	Mean recovery rate of Matalom operator (%)	Row average (%)
Bandsaw	48.3 (13.4)	55.4 (9.5)	52.0
Chainsaw	35.3 (12.4)	40.6 (7.9)	38.8
Column average	43.3	48	46.0

Figures in parentheses are standard errors of the mean. Row and column averages were obtained as averages within groups rather than averages of group averages

Table 4 Two-way ANOVA table for test of effect of saw type and saw operator on recovery rate (%)

Source of variation	Type III sum of squares	Degrees of freedom	Mean square	F	Sig.[b]
Corrected model	5,571.1[a]	3	1,857.1	16.10	0.000
Intercept	203,425.6	1	203,425.6	1,764.10	0.000
Operator	894.3	1	894.3	7.76	0.006
Saw type	4,706.3	1	4,706.3	40.81	0.000
Operator × saw type	33.0	1	33.0	0.29	0.594
Error	11,646.7	101	115.3		
Total	239,030.9	105			
Corrected Total	17,217.8	104			

[a] $R^2 = 0.324$, Adjusted $R^2 = 0.303$

[b] ANOVA was conducted at $\alpha = 0.05$

milling was 52 % and that for chainsaw milling 39 %. ANOVA revealed significant differences in GOS recovery between saw types and between saw operators (Table 4), but interaction between saw type and operator was not significant. From this analysis, it can be concluded that mini-bandsaw milling has higher GOS recovery than chainsaw milling. Further, the Matalom chainsaw miller who had 25 years experience had a significantly higher recovery rate than the chainsaw miller in Bato who had 20 years experience. Also, the Matalom bandsaw miller, who had only one year of experience, achieved a higher recovery rate than the Bato bandsaw miller who had three years of experience. An observation of the researcher on sawing techniques of the bandsaw millers was that the Matalom operator was the more careful in positioning logs on the saw.

Financial Evaluation and Implications of Sawmilling Recovery Rate to Timber Values

An understanding of the impact of the recovery rate on financial returns from logs is necessary for farmers in evaluating timber processing options. Answers to the following questions have been sought:

1. Given a choice between chainsaw and mini-bandsaw, which saw type would yield higher revenue[7] for smallholder timber?
2. What are the revenue levels at various GOS recovery rates?
3. What are the revenue levels from logs at various off-road and on-road hauling distances?
4. What impact do changes of wages of sawmillers, mill running cost and cost of hiring a chainsaw or bandsaw mill have on the timber revenue?

[7] Revenue is defined as the return on logs, net of harvesting (including branch removal and cutting into log lengths), hauling and milling cost.

Table 5 Financial model parameters for free-hand chainsawing and mini-bandsaw milling

Parameter	Chainsaw	Bandsaw
Physical parameter		
Sawn timber recovery rate (%)	39	52
Sawn timber output (m^3/8-h day)	1.23	0.72
On-road distance (km)	10	10
Off-road hauling distance (km)	0.75	0.75
Financial parameter		
Log harvesting cost (PhP/m^3)	740	740
Off-road hauling cost for lumber (PhP/m^3/km)	490	0
Off-road hauling cost for log (PhP/m^3/km)	0	400
On-road hauling cost for log (PhP/m^3/km)	0	100
On-road hauling cost for lumber (PhP/m^3/km)	100	0
Labour cost per day of 2 man crew (PhP/day)	700	500
Wage for operator (PhP/day)	400	300
Wage for helper (PhP/day)	300	200
Hiring cost of mill and accessories (PhP/day)	400	318
Fuel and lubricant for chainsaw cost (PhP/m^3 of log)	600	0
Electricity cost for bandsaw (PhP/m^3 of log)	0	100

Financial model parameters and assumptions

The main objective in the financial evaluation was to determine the potential revenue from 1 m^3 of log sawn by either *on-farm free-hand chainsaw milling* or *fixed-site mini-bandsaw milling*. The analysis has been carried out from the perspective of the smallholder who has a particular volume of standing timber ready for harvest. The question of the smallholder is ‘How much will he earn from 1 m^3 standing timber if it is milled by chainsaw?’ and ‘How much will he earn if it is milled by mini-bandsaw?’ given the cost of *timber harvesting*, *sawmilling* and *hauling of logs or lumber*.

Table 5 presents physical and financial parameters and assumptions for calculating the revenue from 1 m^3 log. In this table, the sawn timber output is the volume of sawn timber produced in 8-h work per day. The off-road distance is the hauling distance from the location of trees to the barangay[8] centre. For off-road transport, manual hauling and carabao hauling are employed for lumber while logs are pulled by a carabao. The higher cost of off-road lumber hauling (Table 5) reflects moving lumber manually or loading lumber on a wooden sled pulled by a carabao. The on-road distance (km) is the distance from barangay to the town centre for which log or sawn timber is hauled by jeepney. The off-road and on-road hauling cost for chainsaw milling is calculated based on the volume of sawn timber while that of bandsaw milling is calculated based on log volume. It is assumed that customers will pick up timber at the mini-bandsaw mill.

[8] A barangay is the smallest political unit in the Philippines, and is a component of a municipality or city.

Table 6 Estimated gross value of sawn timber by sawmilling type (PhP/m^3)

Cost	Chainsaw	Bandsaw
Felling and bucking (PhP)	740	740
Transport cost		
Hauling off-road cost in log equivalent (PhP)	143	300
Hauling on-road cost in log equivalent (PhP)	390	1,000
Labour cost (PhP)	222	361
Mill cost		
Mill operating cost (PhP)	234	52
Rent on machine and accessories (PhP)	127	230
Total cost (PhP)	1,856	2,683
Sawn timber market value (PhP)	2,976	3,969
Revenue (PhP/m^3)	1,120	1,286

The timber harvesting cost (PhP/m^3 of log) includes felling the trees, removal of branches and cutting to log lengths. The labour cost of milling was estimated for a 2-man crew working an 8-h day. According to chainsaw millers interviewed, the high labour rate they charge is due to the unfavourable working condition in chainsaw milling, e.g. milling on sloping ground, unsheltered milling site (working rain or shine) and often sleeping in makeshift huts. The mill hiring cost includes payment for use of the mill and its sundry tools and cost of saw sharpening. The average market price for gmelina sawn timber was assumed at PhP 7,632/m^3 (424 bf by PhP18/bf).[9]

Estimated gross timber value and financially feasible sawmilling options for smallholders

On the basis of the parameters in Table 5, the revenue with free-hand chainsaw milling is PhP 1,120/m^3 of log while that for mini-bandsaw milling is PhP 1,286/m^3 of log (Table 6). In that the timber value assumed in this revenue calculation represent for the lowest value timber product, these net revenues represent the floor stumpage price. This floor stumpage price for smallholder gmelina timber in Leyte is lower than the floor stumpage price of about PhP 1700/m^3 in Mindanao reported by Bertomeu (2008). Although the total production cost of bandsawing is considerably higher than of free-hand chainsaw milling, a higher net revenue is obtained with mini-bandsaw milling due to the higher GOS recovery rate.

Figure 4 presents the revenue of 1 m^3 of log at varying sawn timber recovery rates under chainsaw milling and mini-bandsaw milling. The intersection of the revenue lines for chainsaw milling and mini-bandsaw milling is the sawn timber recovery rate at which the two milling option are at about parity, at 80 %. Figure 4 indicates that if chainsaw milling achieves a recovery rate the same as that of mini-

[9] PhP18/bf is the market price for short and low quality sawn timber boards and therefore is a conservative estimate of timber value. The peso-dollar exchange rate was PhP 45 = US $1.

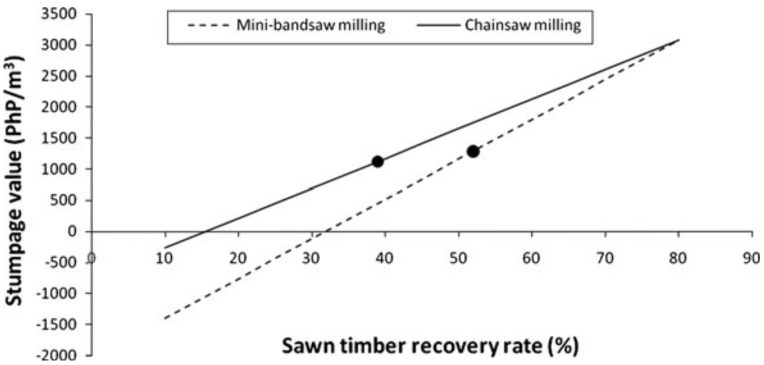

Fig. 4 Estimated revenue from chainsaw milling and mini-bandsaw milling of logs at varying sawn timber recovery rates

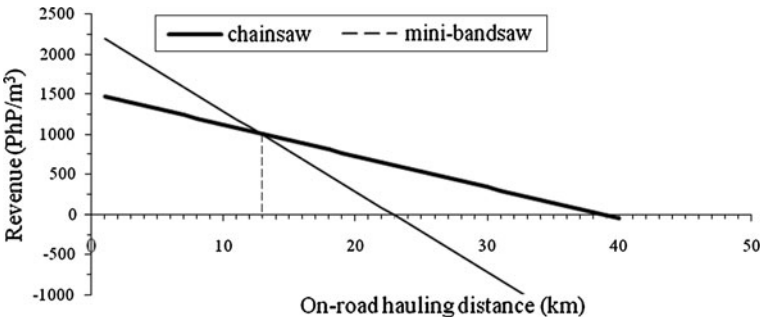

Fig. 5 Timber revenue for a range of on-road hauling distances (PhP/m^3 of log)

Table 7 Scenario analysis of small-scale chainsaw and bandsaw milling financial model

Parameter	Chainsaw milling			Bandsaw milling		
	Current value	Pessimistic value	Optimistic value	Current value	Pessimistic value	Optimistic value
Wage of operator (PhP/day)	400	480	320	300	360	240
Wage of helper (PhP/day)	300	360	240	200	240	160
Mill hire (PhP/day)	400	480	320	318	382	254
Mill running cost (PhP/day)	600	720	480	100	120	80
Revenue (PhP/day)	1,120	1,004	1,237	1,286	1,157	1,414

bandsaw milling, chainsaw millers could offer stumpage values higher than what bandsaw millers could offer due to the lower cost of chainsaw milling. It is shown in Fig. 5 that revenue of mini-bandsaw milling is at parity with chainsaw milling for an on-road hauling distance between 12 and 13 km. When the mini-bandsaw mill is 13 km or less from the tree its revenue is higher than for chainsaw milling; when the mini-saw mill is farther than 13 km, chainsaw milling yields a higher revenue.

A scenario analysis was conducted in which the labour cost, hiring cost of the mill and mill running cost were varied simultaneously by plus and minus 20 % (pessimistic and optimistic levels) to evaluate their aggregate impact on revenue. As indicated in Table 7, changes in labour cost, mill rent and running costs have little impact on sawn timber value for both timber milling options under a number of assumptions considered in the financial model. The net change of revenue with ±20 % simultaneous change in the above four parameters for chainsaw milling is PhP 116/m^3 while that of bandsaw milling is PhP 129/m^3. In that the revenue represents a floor stumpage price of smallholder gmelina timber, the scenario analysis suggests that ±20 % change on the levels of this variables correspond to a modest 10 % change n stumpage value, assuming all other variables in the model are held constant.

Conclusion

The sawing trials conducted in Leyte Island revealed that off-site mini-bandsaw milling has significantly higher GOS recovery than on-site chainsaw milling, with rates of 52 and 39 % respectively. The financial analysis reveals that due to higher GOS recovery of mini-bandsaw mills, the revenue for mini-bandsaw mill is PhP 168/m^3 higher than on-farm chainsaw milling. It was further found that when sawing recovery rate of the two milling options are the same, chainsaw milling has higher revenue due to considerably lower transport and milling labour cost. Furthermore, when the mini-saw mill is farther than 13 km, chainsaw milling is a better option because revenue from chainsaw milling is higher than from bandsaw milling beyond 13 km on-road hauling distance.

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